City Transport Monitoring and Routes Management System

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Introduction

Fast improvement of computers, automation systems, communications, mechatronic means allows Intellectual Transport Control Systems (ITCS) [1-4] to develop rapidly, which gives a possibility to optimally use existing infrastructure of city transport, and for the road users to choose the best (in accordance with the criteria chosen by the driver: time, fuel consumption, accident risk and etc.) route in the current situation.

Most of all traffic route optimal criterion is their transit time. The optimal time of track overcome is the most important criteria for many drivers.

To find the shortest in respect of time (the fastest) route one essential addition to the nowadays available GIS-TMC [2] system would be enough: a dynamic (automatically updated in real time) street passing duration base should be created.

Unfortunately, support of street passing duration base is impossible without creation of transport monitoring system operating in real time and consisting of sensors network, data collection communications system and data processing system. The structural diagram of such system is shown in Fig. 1.

Street passing time

The street \( G_{ij} \), which length is \( l_{ij} \), is passed on the average during the time \( \tau_{ij} \) consisting of 5 parts:

1) \( \tau_{ij}^0 \) - time necessary to cover the distance \( l_{ij} \) driving at the driving speed \( v_{ij}(t) \);
2) \( \tau_{ij}^{sta} \) - time wasted braking at the restrictive signals of the traffic lights;
3) \( \tau_{ij}^{st} \) - time wasted standing by the restrictive signals of the traffic lights;
4) \( \tau_{ij}^{gr} \) - time wasted to accelerate after standing to the speed \( v_{ij}(t) \) [1, 2];
5) \( \tau_{ij}^{zst} \) - time wasted a certain road user who „catch up with“ the row as the traffic light signal was already green

\[
\tau_{ij} = \tau_{ij}^0 + \tau_{ij}^{sta} + \tau_{ij}^{st} + \tau_{ij}^{gr} + \tau_{ij}^{zst}.
\] (1)

The time \( \tau_{ij}^{sta} \) wasted standing by restrictive traffic light signal consists of two parts:

1) time of standing by the red signal \( \tau_{ij}^{sta-r} \) (from stop to lighting of permissive (green) signal);
2) time \( \tau_{ij}^{st-p} \) of starting after the permissive (green) signal appears.

That, if traffic lights of the street \( G_{ij} \) are tuned in the “green wave” mode, average passing duration of this street (from the first to the last crossroad) is [2]:

\[
M[T_{ij}] = \left(1 - \frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \right) I_{ij} + \\
+ \frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \left( 2 + \frac{v_{tij}(t)}{a} \right) + \\
+ \tau_{ij}(t) T_{cal} + T_{rad} + \\
+ \frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \frac{2(v_{tij}(t))^2}{2(T_{cal} + T_{rad})} + \\
\frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \frac{al_{ij} - (v_{tij}(t))^2}{av_{tij}(t)}. \tag{2}
\]

Here \( T_{rad}, T_{cal} \) – effective duration of red and green traffic light signals [s]; \( n_{ij}(t) \) – traffic density [number of vehicles per second]; \( \tau_{ij} \) – time [s] of the driver’s reaction (to starting of a vehicles standing in front of him).

It should be noted that average time of waiting \( \tau_{ij}^{st-z} \) is calculated by a formula

\[
M[T_{ij}] = \left(1 - \frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \right) I_{ij} + \\
+ \frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \left( 2 + \frac{v_{tij}(t)}{a} \right) + \\
+ \tau_{ij}(t) T_{cal} + T_{rad} + \\
+ \frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \frac{2(v_{tij}(t))^2}{2(T_{cal} + T_{rad})} + \\
\frac{(1 + \tau_{ij}(t)v_{tij})T_{cal} + T_{rad}}{v_{tij}(t)} \frac{al_{ij} - (v_{tij}(t))^2}{av_{tij}(t)}. \tag{3}
\]

If \( M[T_{ij}]^{st-z} \geq \frac{1}{n_{ij}(t)} \), row of cars by the red signal continually lengthen and develop a gridlock.

This process must be analyzed in separate.

**Gridlocks dynamic analysis**

There is a situation when the traffic jam are in \( L \) km street width is \( L_{sp} \) km (fig. 2).

The speed in the transport traffic jam is \( v_1 \), in the rest distance of the street speed is \( > v_0 \).

The traffic jam between next to transport vehicles is described by formula

\[
L = l + 1.8 \ v_{ml1}. \tag{4}
\]

In the rest of the street distance between contiguous vehicle is

\[
L_p = L_0 + L_a. \tag{5}
\]

where \( L_0 \) – a minimal gap between two vehicles when \( v = v_0 \), \( L_a > 0 \),

One vehicle (in Fig. 2 is marked with red square) is approaching to transport jam at the point \( x \), which is \( \Delta \) length far from “0”. At this point traffic jam was reached by second vehicle before (in fig. 2 is marked with green square). In case when \( \Delta > 0 \) traffic jam is about to extinct.

How to find out \( \Delta \) length ?

The “green” car distance \( \Delta + L_1 \) takes in

\[
T = \frac{\Delta + L_1}{v_1} = \frac{\Delta + l + 1.8v_1}{v_1}, \tag{6}
\]

here \( L \) – vehicle average length.

Formula (6) works if \( v_1 > 0 \), this means that traffic jam must move at least average minimal speed. For unmovning traffic jam this formula is useless.

If traffic jam is unmovning – the street transit time numeration has no sense.

The “red” car time \( T \) has to intervals: \( T_0 \) - when the speed of the car is \( v_0 \), and \( T_s \) - when the car slow down the speed from \( v_0 \) till \( v_1 \)

\[
T = T_0 + T_s. \tag{7}
\]

If the car stops constant acceleration \( a \), then

\[
T_s = \frac{v_0 - v_1}{a}. \tag{8}
\]

The distance of the stopping moment

\[
S_s = v_0T_s - \frac{aT_s^2}{2} = \frac{v_0^2 - v_1^2}{2a}. \tag{9}
\]

It is easy to see from figure 2 that “red car” goes distance constant speed \( v_0 \)

\[
S_0 = L_p + \Delta - S_s. \tag{10}
\]

It takes \( T_0 \), time to pass distance \( S_0 \), witch one can describe formula (5), (9) and (10).
\[ T_0 = \frac{L_0 + L_a + \Delta - \frac{v_0^2 - v_1^2}{2a}}{v_0} . \]  

From formula (6), (7), (8) and (11) we get equation
\[ \frac{2al_a + 2al_a + 2a\Delta - \frac{v_0^2 - v_1^2}{2a} + 2v_0v_1}{2av_0} = \frac{\Delta + l + 1,8v_1}{v_1} . \]  

Ordered equation
\[ \Delta = \frac{v_1(v_0 - v_1)^2 - 3.6av_0v_1 - 2alv_0}{2a(v_0 - v_1)} + \frac{v_1}{v_0 - v_1}(L_0 + L_a) = b + c(L_0 + L_a) . \]

According to formula (4), \( L_0 + L_a = \frac{v_0}{I} \), formula (13) gets form
\[ \Delta = b + cv_0 \frac{1}{I} , \]  

here \( I \) – intensity of traffic flood till traffic jam limit;
\[ b = \frac{v_1(v_0 - v_1)^2 - 3.6av_0v_1 - 2alv_0}{2a(v_0 - v_1)} ; \]  

\[ c = \frac{v_1}{v_0 - v_1} . \]  

According to formula (6) and (13) can make conclusion that the traffic jam is getting shorter by speed.
\[ v_{sp} = \frac{\Delta}{I} = \frac{\Delta v_1}{\Delta + l + 1,8v_1} , \]  

or quantified (14),
\[ v_{sp} = \frac{bv_1 l + cv_0v_1}{bI + cv_0 + l + 1,8v_1} . \]

The traffic jam length is changing linearly. Passing time of the street \( G_y \)
\[ T_y = t_{y-sp} + t_{y-l} , \]  

here \( t_{y-sp} \) – the traffic jam time; \( t_{y-sp} \) – time going street \( G_y \) till traffic jam.

The traffic jam speed is \( v_1 \), but speed till the traffic jam it is \(- v_0\).

\[ T_y = \frac{L_y(0) - v_{sp}t}{v_1} + \frac{L - L_y(0) + v_{sp}t}{v_0} . \]  

Transforming the formula (19)
\[ T_y = L + \frac{v_0 - v_1}{v_0v_1} \left( L_y(0) - \frac{bv_1 l + cv_0v_1}{bI + cv_0 + l + 1,8v_1} t \right) . \]  

It is important to see that \( 0 < t \leq \frac{L_y(0)}{v_{sp}} \).

Conclusions

1. Traffic jams problem in the cities could be relieved by installation of information systems showing to road users in real time the fastest (the shortest in respect of passing time) routes. Such systems need dynamic street passing duration’s base for functioning which is possible only after creation of an automatic city transport monitoring system.

2. To evaluate a street passing duration it would be enough to measure average speed of vehicles and traffic density in its characteristic parts.

3. To find street passing durations is possible to use in this article presented methodology.

References


The article analyzes a problem of further development of traffic control informational systems in order to present to the road users effective information about the shortest in respect of time routes and thus to improve use of existing city transport infrastructure. To solve this task it is suggested to create dynamic (automatically updated in real time) street passing durations base, for support of which a city transport monitoring system operating in real time is necessary consisting of a network of sensors, a data collection communications system and a data processing system. In the article it is shown that to predict a street passing duration it is necessary to measure speed and traffic density in the characteristic points of the street. Measurements of do not significantly improve accuracy of forecast of a street passing time. Methodology are presented meant to forecast a street passing time.

